Available online at www.sciencedirect.com

SCIENCE DIRECT®

Renewable and Sustainable Energy Reviews
11 (2007) 315–330

RENEWABLE
& SUSTAINABLE
ENERGY REVIEWS

www.elsevier.com/locate/rser

Assessment of cleaner electricity generation technologies for net CO_2 mitigation in Thailand

Bundit Limmeechokchai[a,*], Pawinee Suksuntornsiri[b,c]

[a]Sirindhorn International Institute of Technology, Thammasat University, Thammasat Rangsit Post Office, P.O. Box 22, 12121 Pathumthani, Thailand

[b]The Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi, Bangkok, Thailand

[c]Department of Mechanical Engineering, Faculty of Engineering, Burapha University, Chonburi 20231, Thailand

Received 20 December 2004; accepted 7 January 2005

Abstract

The choice of electricity generation technologies not only directly affects the amount of CO_2 emission from the power sector, but also indirectly affects the economy-wide CO_2 emission. It is because electricity is the basic requirement of economic sectors and final consumptions within the economy. In Thailand, although the power development plan (PDP) has been planned for the committed capacity to meet the future electricity demand, there are some undecided electricity generation technologies that will be studied for technological options. The economy-wide CO_2 mitigations between selecting cleaner power generation options instead of pulverized coal-thermal technology of the undecided capacity are assessed by energy input–output analysis (IOA). The decomposition of IOA presents the fuel-mix effect, input structural effect, and final demand effect by the change in technology of the undecided capacity. The cleaner technologies include biomass power generation, hydroelectricity and integrated gasification combined cycle (IGCC). Results of the analyses show that if the conventional pulverized coal technology is selected in the undecided capacity, the economy-wide CO_2 emission would be increased from 223 million ton in 2006 to 406 million ton in 2016. Renewable technology presents better mitigation option for replacement of conventional pulverized coal technology than the cleaner coal technology. The major contributor of CO_2 mitigation in cleaner coal technology is the fuel mix effect due to higher conversion efficiency. The demand effect is the major contributor of CO_2 mitigation in the

*Corresponding author. Tel.: +66 2 986 9009x2206; fax: +66 2 986 9112.
E-mail address: bundit@siit.tu.ac.th (B. Limmeechokchai).

doi:10.1016/j.rser.2005.01.006

biomass and hydro cases. The embedded emission in construction of power plant contributes to higher CO_2 emission.

Keywords: Full-energy-chains analysis; CO_2 emission; Cleaner power plant technology; Input–output analysis

Contents

1. Introduction

Indigenous fossil energy resource in Thailand is limited while the only major domestic fossil resource is the natural gas. The experience of the world impact by energy crisis since 1963 has enforced the fuel mix in the power generation scheme transformed to lower generation from fuel oil [1]. Thereafter, the public awareness of local pollution from the existing lignite power plant also retards implementations of the new coal-fired power plants. Under frustration, the Electricity Generation Authority of Thailand (EGAT), a government enterprise who is responsible for the country electricity supply, is solving mainly the supply-side problem by introducing additional natural gas for power generation [2]. The more share of natural gas in power generation, the more difficulty in the grid power scheme since the proved reserve of domestic natural gas is estimated for serving only 18 years in the future [3].

In 2003, natural gas contributes 71%, whereas coal and lignite, hydro, and fuel oil contribute 17, 8.5, and 2.5%, respectively, to the grid electricity generation mix [4]. Other renewable energy share is less than 1% of total electricity generation. If the additional capacity is relied on natural gas-based plant, the natural gas dependency would reach 85% in 2006 [1]. High dependency on natural gas reflects the high risk of the national generation scheme under instability and fluctuation of future natural gas price [5]. The decreasing of natural gas-based plants from 2001 to 2016 of the 2003 power development plan, called PDP2003 plan, implies that the policy makers attempt to diversify fuel-mix in electricity generation. However, the PDP2003 plan shows that the generation mix during 2011–2016 has not been decided yet.

Currently, the Ministry of Energy has emphasized on the promotion of renewable energy in electricity generation [6]. The renewable energy plants have been contributed to the national grid by the Small Power Producers Programme (SPP), a subsidizing program since 1998. SPP-renewable energy contribution in 2002 is 313 MW. 89.4% of them are biomass, and 10.6% is hydro [4]. As of December 2003, cumulative capacity of renewable energy proposed to the grid is 276 MW. In 2003, the Renewable Energy Strategic Plan has been announced. It aims at increasing renewable energy penetration from 265 toe in 2002 to 6540 toe within 8 years [7]. In April 2004, the Renewable Portfolio Standard (RPS) has been introduced by the Ministry of Energy, and it will enforce 5% of total electricity generation from renewable energy.

The climate change has become a new agenda in long-term energy planning. Thailand, a non-Annex I country, has published the first 'National GHGs Inventory of 1990' since 1997 and it was updated to 1994 inventory in 2000 [8]. It is reported that the country's CO_2 emission is 202 ton. The energy sector emits up to 125 ton, and 36% of CO_2 emission comes from transformation of energy to electricity.

In this study, the economy-wide CO_2 emissions affected by the changes in power generation technology are assessed by input–output analysis (IOA). Due to the change in generation mix by substitution the conventional coal technology with cleaner technologies, there exists mitigation effect in the economy-wide CO_2 emission [9]. The PDP2003 plan [4] is used as the basis in the alternative policy options to make the study closer to the practical situation. The undecided capacity is tested with cleaner options. The components affecting the total emissions are presented by input–output (I–O) decomposition. Net CO_2 emissions due to changes in fuel mix, input-structure of the power sector, final demand, and investment of the new power plant construction are assessed. Total emissions and mitigation in the different policy options of conventional coal thermal, integrated gasification combined cycle (IGCC), biomass thermal, biomass integrated gasification combined cycle (BIGCC) and hydro power plants are presented.

2. Power development plan and additional capacity

The Thailand Load Forecast Subcommittee (TLFS) has projected that the annual electricity demand will be increased from 117,500 GWh in 2003 to 250,000 GWh in 2016 [4]. In order to meet the future electricity demand, EGAT has provided the PDP2003 plan. The PDP2003 plan presents the plan for additional capacity for the period 2003–2016 (see Fig. 1). The committed capacities are fully decided before 2009. The plant types of additional capacities that are not yet decided are 700 MW in 2010 and up to 13,060 MW until 2016. Scenarios of alternative policy options in the undecided capacity are assessed in this article.

3. Methodology

This study disaggregated electricity generation sector into 8 sectors by type of fuel. Various effects of changes in the power sector on the economy-wide CO_2 emission are derived by the relationship between the power sector and other sectors within the economy as presented in Fig. 2. Selection of a particular electricity generation technology will affect the change in electricity final demand from that sector and the change in fuel mix in that sector. The change in final demand and the change in fuel mix would indirectly affect the

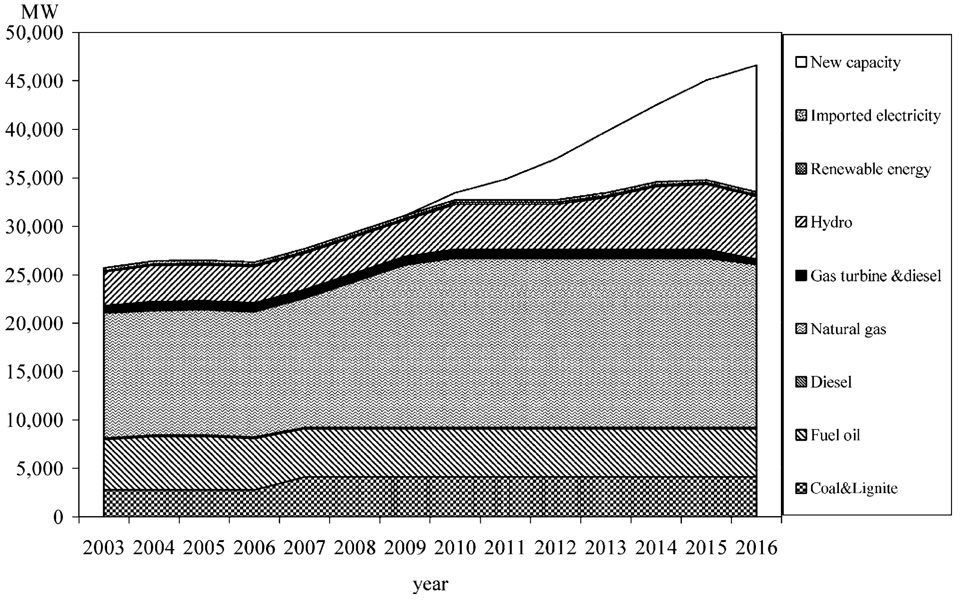


Fig. 1. EGAT's power development plan (PDP2003).

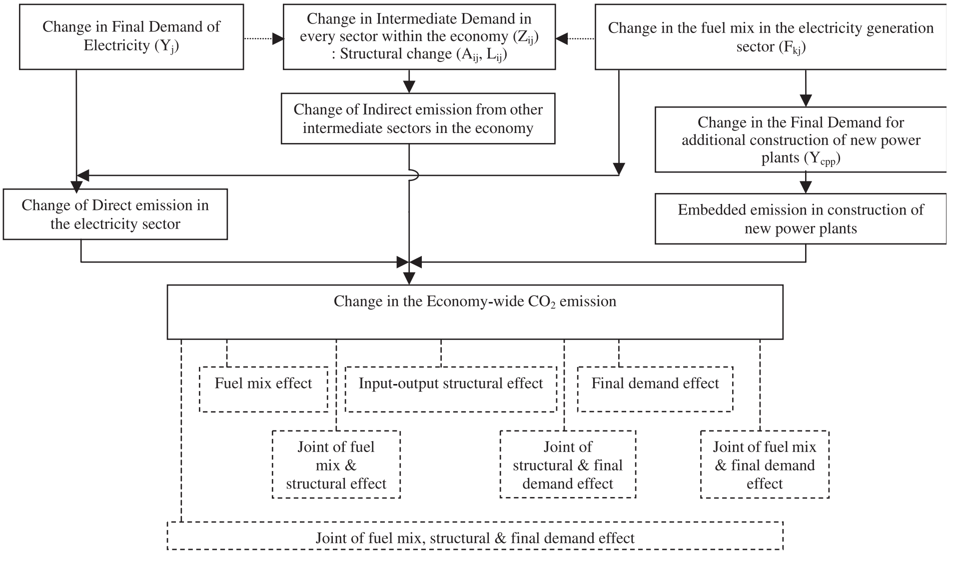


Fig. 2. Effects related to electricity generation to the economy-wide CO_2 emission and decomposition of various effect.

change in input structure of that electricity sector, and also demands for additional power plant. The change in final demand of electricity and the change in fuel mix would yield the change in the amount of direct CO_2 emission from the considered electricity sector. The change in indirect emission from other intermediate sectors and embedded emission in the

demand in power plant construction constitutes indirect emissions. The summation of direct emission and indirect emission is the total emission from the economy or the economy-wide CO_2 emission.

In order to evaluate the economy-wide impact of alternative policy options of electricity generation expansion plan, the economic-IOA is used in this study. By IOA principal, an economy is classified into n sectors, where $n = 1, 2, \ldots, i, \ldots, j, \ldots, n$. To produce an amount of final consumption y_i, intermediate consumptions z_{ij} are needed for interindustrial transactions among intermediate sectors, from sector i to sector j, in the economy. If x_j is the total output of sector j, and a_{ij} is defined z_{ij}/x_j. The total output of sector j caused from 1 unit demand of final consumption j is $x_j = \Sigma a_{ij} + y_j$. The final demand y_j comprised of private consumption, government consumption, investment, and increase in stock. The final consumption of the economy is defined in matrix $\mathbf{Y} = [\mathbf{I} - \mathbf{A}]\mathbf{X}$, and the total output; $\mathbf{X} = [\mathbf{I} - \mathbf{A}]^{-1}\mathbf{Y}$. $\mathbf{Y}$ is the vector of final demand. $\mathbf{I}$ is the unity matrix. $\mathbf{A}$ is the structural matrix constituted from a_{ij} elements, and $\mathbf{X}$ is the matrix of total output constituted from x_{ij} elements.

Let $\mathbf{G}$ be the total energy demand matrix and $\mathbf{P}$ be the matrix of total emissions from the economy, the total energy demand from the economy is $\mathbf{G} = \mathbf{F}[\mathbf{I} - \mathbf{A}]^{-1}\mathbf{Y}$, and total environmental emission from the whole economy is $\mathbf{P} = \mathbf{EF}[\mathbf{I} - \mathbf{A}]^{-1}\mathbf{Y}$.

Proop et al. [10] has firstly introduced decomposition I–O economics to classified final demand effect and structural effect of total energy consumption in an economy. Marpaung [11] applied the decomposition IOA to classify various effects of the total CO_2 mitigation options through carbon tax in the power sector in Indonesia. The total economy-wide CO_2 emission caused by the change in fuel mix $\mathbf{\Delta F}$, the change in I–O structure $\mathbf{\Delta L}$, and the change in final consumption $\mathbf{\Delta Y}$ is

$$\mathbf{\Delta P} = \mathbf{EF'L'Y'} - \mathbf{EF_0L_0Y_0}$$

If $\mathbf{\Delta F} = \mathbf{F}' - \mathbf{F}_0$, $\mathbf{\Delta L} = \mathbf{L}' - \mathbf{L}_0$, and $\mathbf{\Delta Y} = \mathbf{Y}' - \mathbf{Y}_0$, the economy-wide emission could be decomposed to seven components i.e. fuel-mix effect ($\mathbf{E\Delta FLY}$), structural effect ($\mathbf{EF\Delta LY}$), final demand effect ($\mathbf{EFL\Delta Y}$), joint of fuel-mix and structural effect ($\mathbf{E\Delta F\Delta LY}$), joint of fuel mix and final demand effect ($\mathbf{E\Delta FL\Delta Y}$), joint of structural and final demand effect ($\mathbf{EF\Delta L\Delta Y}$), and joint of fuel-mix and structural and final demand effect ($\mathbf{E\Delta F\Delta L\Delta Y}$).

The total effect means the change in CO_2 emissions of the whole economy caused by the change in the power sector. Hence, the direct effect is the change in CO_2 emissions in the power sector. The fuel-mix effect is the effect of the change in physical amount of fuel supplied to the producing sector. The structural effect is caused from the change in monetary transactions by the change in purchased fuels from fuel-supplied sector to the producing sector. The final demand effect is the change in final consumptions in various economic sectors caused from switching of the electricity demand from one producing sector to another. They include electricity demand and demand for construction of new power plants.

4. Input data and assumptions

4.1. Input–output data

The 1998 I–O table of Thailand released by the National Economic and Social Development Board (NESDB) used in this study, is composed of 180×180 input and

Table 1
Disaggregation of the power sector

Power sector (j)	Member of disaggregated power sector (plant type)	Fuel consumption (k)
Coal electricity	Coal thermal	Coal
	Integrated gasified combined cycle (IGCC)	
	PFBC	
Lignite electricity	Lignite thermal	Lignite
Natural gas electricity	Gas turbine	Natural gas
	Combined cycle	
Fuel oil electricity	Fuel oil thermal	Fuel oil
Diesel oil electricity	Diesel oil thermal	Diesel oil
	Diesel oil gas turbine	
Biomass electricity	Bagasse thermal electricity	Bagasse
	Paddy	Paddy husk
	Wood thermal electricity	Wood, saw mill waste
	Corncob	Corncob
	Cassava	Cassava
	Biomass integrated gasified combined cycle (BIGCC)	Wood
Hydro electricity	Hydro power plant	–
	Small hydro power plant	
Other renewable electricity	Wind turbine power plant	–
	Solar thermal power plant	
	Solar photovoltaic plant	

output sectors [12]. Since this study focuses on fuel types in the power generation, the power sector is disaggregated into thermal and hydro plants as shown in Table 1. All sectors that related to input factors for operation of any types of power plants are not changed, and sector aggregation is applied to the other sectors. The new size of I–O table, which will be used to assess the economy-wide environmental emissions, is 50×50 I–O sectors. The description of the aggregated I–O table related to the original 180×180 I–O table is given in Appendix A.

Since this study is based on the total electricity demand forecasted by the TLFS, there is no change in final demand in the power sector. The only final demand of other sectors occurred is the demand for construction of electric plants ($\mathbf{Y_{cpp}}$) due to the change in generation mix.

4.2. Descriptions of technology options

The committed plants in the PDP2003 plan are considered, but the additional capacity that is not yet decided is considered for alternative options for comparison of total CO_2 emissions. This study assesses four scenarios of plant types of the additional capacity in the period 2011–2016. In order to decrease the imported natural gas dependency, the alternative policy options will not include any additional natural gas-based plants.

The technologies installed in the additional capacity during 2010–2016 are presented in Table 2.

Table 2
Technologies options for additional capacity during 2010–2016

Case	Plant type	Technology for additional capacity during 2010–2016	Construction cost (million Baht)
Base case	PDP2003	Coal steam thermal plants	886,421
IGCC case	PDP2003	IGCC-coal	883,056
Biomass case	PDP2003	Biomass thermal: Bagasses, Paddy, Wood, Corncob, and Cassava BIGCC-wood	923,354
Hydro case	PDP2003 + purchased from Myanmar	Minihydro Biomass thermal: Bagasses, Paddy, Wood, Corncob, and Cassava BIGCC-wood	1,021,740

In the biomass case, total potential of various biomass fuels are installed firstly and the remaining capacity is installed by biomass integrated gasification combined cycle (BIGCC). In the hydro case, imported electricity from hydropower from Myanmar is added to the recommended plan and the remaining capacity is all installed by total potential of biomass and BIGCC.

In the IGCC case, the practice of clean coal technology is evaluated in the additional capacity in the integrated gasification combined cycle (IGCC) case since it is a more efficient clean coal technology that is possibly introduced by EGAT [13]. Technical details and characteristics of candidate power plants are presented in Table 3. Payments for construction of additional power plants are assumed to be spent on the year prior to the first commissioning year.

4.3. Biomass potential

Thailand is an agricultural-based country, and biomass potential for energy conversion is high. Biomass potential is obtained from the Department of Alternative Energy Development and Efficiency (DEDE) and converted to electricity generation capacity as presented in Table 4. However, the electricity demand forecast shows a high capacity requirement. Only the total waste from available biomass is not enough to fulfill total capacity requirement in 2006. In addition, the remaining capacity is installed by BIGCC and large plantation of wood is needed in this case.

4.4. Forecast of final demand

The 1998 I–O table of Thailand [12] and energy I–O data [16] are used for energy I–O analysis. Total electricity demand during 2006–2016 forecasted by the TLFS is used for the supply side options in this study. It is the economy-wide electricity demand comprising intermediate electricity demand plus final electricity demand. Forecast of final demand is required for IOA. The growth of electricity demand used by the TLFS is used in this study [4]. The final demand of other commodities in the economy is projected from the commodity final demand in the I–O table in 1998 by the gross domestic product (GDP) growth [17].

Table 3
Characteristics of candidate power plants

Plant name	Plant type	Fuel type	Calorific value[a] (Gcal/ton)	Price[a] (US$/Gcal)	Capacity (MW)	Cost at 2000 price[a] (US$/kW)	Heat rate[b] (Btu/kWh)
Coal	Coal steam	Imported coal	6.3	6.27	370 and 700	837	9720
IGCC	IGCC	Imported coal	6.3	6.27	540	1420	7346
Bagasse	Biomass thermal	Bagasse	1.8	2.13	20	1510	11,482
Paddy	Biomass thermal	Paddy	3.44	1.01	12	1510	11,482
Wood	Biomass thermal	Wood	3.82	4.27	25	1510	11,482
Corncob	Biomass thermal	Corncob	3.03	2.34	20	1510	11,482
Cassava	Biomass thermal	Cassava	3.03	0.21	25	1510	11,482
BIGCC	BIGCC	Wood	3.82	4.27	500	1626	9728

[a]Source SIIT (2004) [14].
[b]Source DEDE (2003) [15].

Table 4
Biomass resource potential for electricity generation

Biomass type	Residue[a] (Mton/yr)	Electricity production (GWh/year)	Capacity (MW)
Bagasse	16.8	11,024	1258
Paddy	7.45	9343	1067
Wood	2.85	3969	453
Corncorb	7.759	8571	978
Cassava	2.989	3302	377
Total		36,209	4133

[a]Source SIIT (2004) [14].

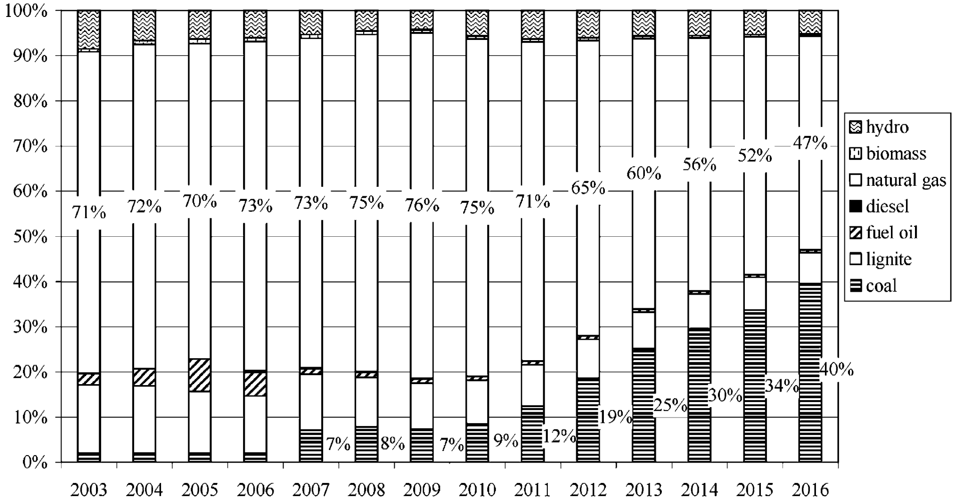
4.5. CO_2 emission factor

This study used the method of the revised 1996 IPCC guidelines [18–20] for CO_2 emission by combustion activity in the energy sector. In order to avoid double counting, secondary energy is not accounted for emission evaluation except imported secondary energy. CO_2 emission by combustion of biomass is considered as net zero emission from the closed carbon cycle.

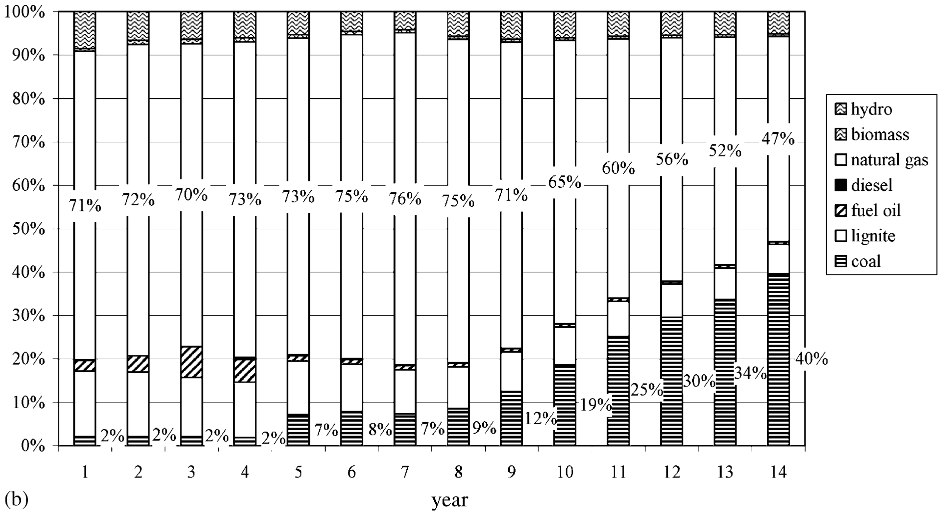
5. Results

Fig. 3(a)–(d) present share of electricity generation by fuel type from 2003 to 2016. Under the PDP2003 plan, electricity generation from natural gas would increase from 71%

in 2002 to 76% in 2009. From 2009 to 2016, all cases present reduction of electricity generation by natural gas from 76% in 2009 to 47% in 2016. In the base case, shown in Fig. 3(a), and the IGCC case, shown in Fig. 3(b), the share of electricity generation from natural gas switches to coal. The share of electricity generation from coal would increase from 2% during 2002–2006 to 40% in 2016, respectively. The share of electricity generation from biomass in the biomass case, shown in Fig. 3(c), and the hydro case, shown in Fig. 3(d), would increase from 1% during 2002–2009 to 35% and 34%, in 2016, respectively. The electricity generation from hydro power plant would be 7% during 2013–2015 and 6% in 2016.

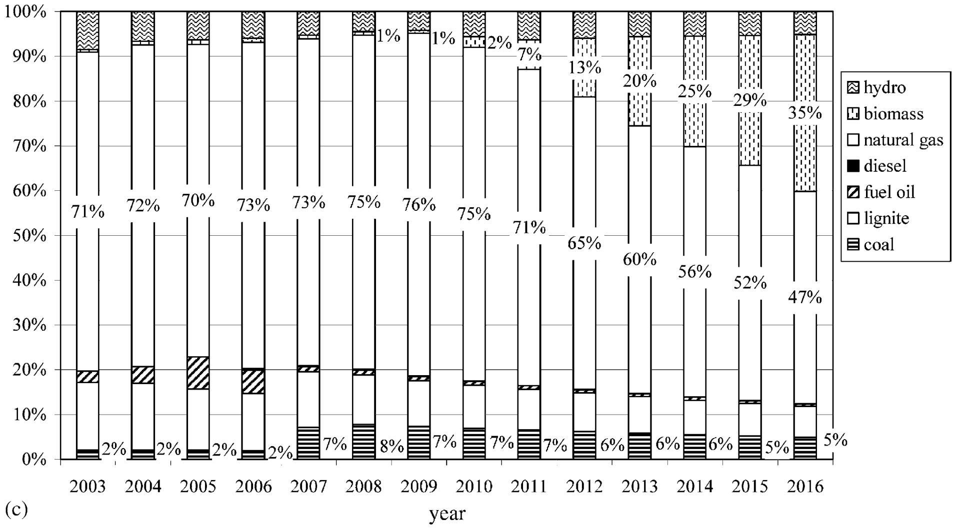


(a)

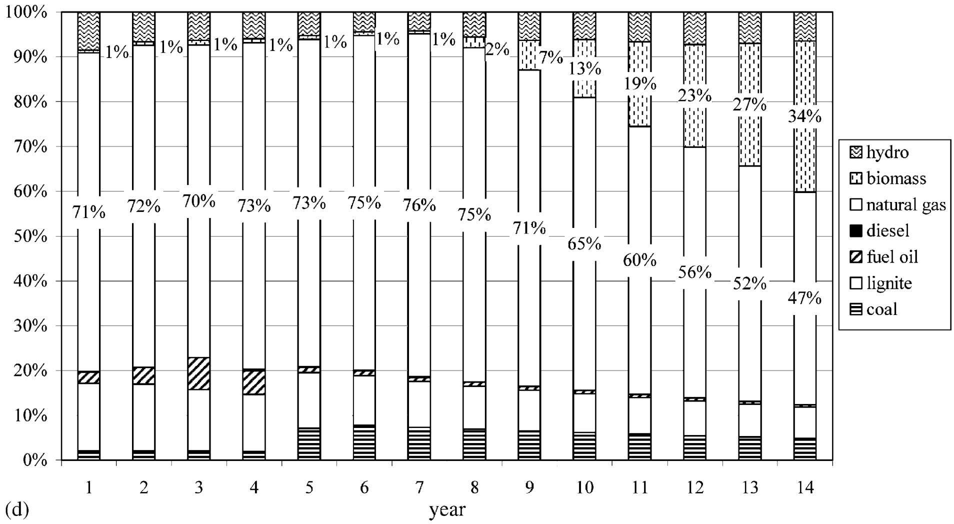


(b)

Fig. 3. Share of electricity generation by fuel type in the base case. (b) Share of electricity generation by fuel type in the IGCC case. (c) Share of electricity generation by fuel type in the biomass case. (d) Share of electricity generation by fuel type in the hydro case.



(c)



(d)

Fig. 3. (*Continued*)

Expected coal consumption in all cases is presented in Fig. 4. The base case requires 35,000 ton of coal in 2016. The IGCC case require 28,000 ton of coal in 2016. The smaller coal requirement is due to higher efficiency of coal conversion technology.

Comparison of various type of required biomass consumption in each case is presented in Fig. 5 The base case requires very small fraction of biomass. The biomass and hydro cases require all available potential of bagasse, paddy, corncorb and cassava, and also require large amount of wood plantation during 2015–1016.

In the base case, the total CO_2 emission is 223 million ton in 2006, and 405 million ton in 2016 (see Fig. 6). The cumulative direct CO_2 emission in the power sector during 2006–2016 is 1139 ton in the base case (see Table 5). Without consideration of embedded

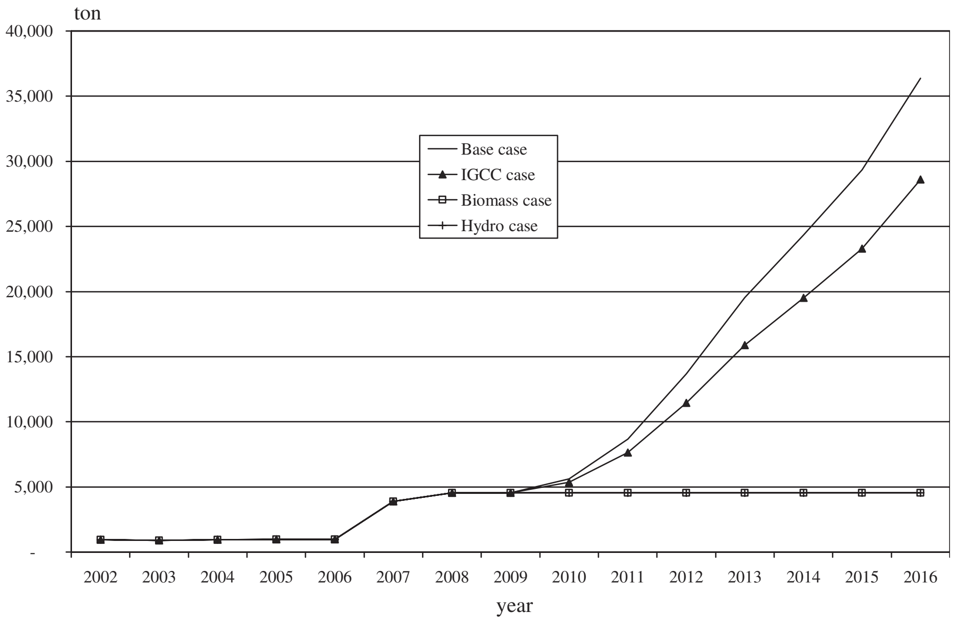


Fig. 4. Expected coal consumption in the power sector for all cases.

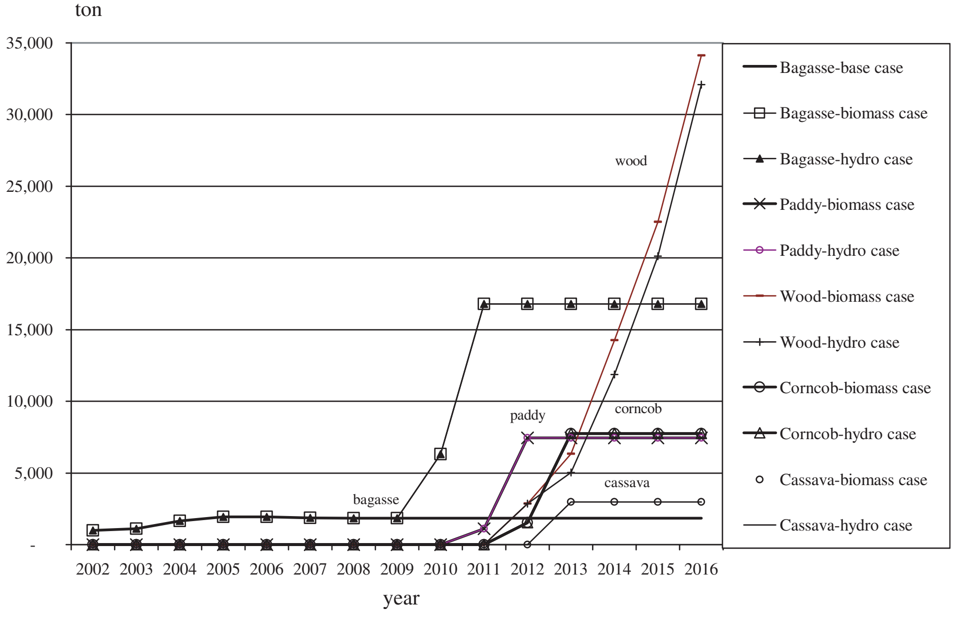


Fig. 5. Expected biomass consumptions in the power sector.

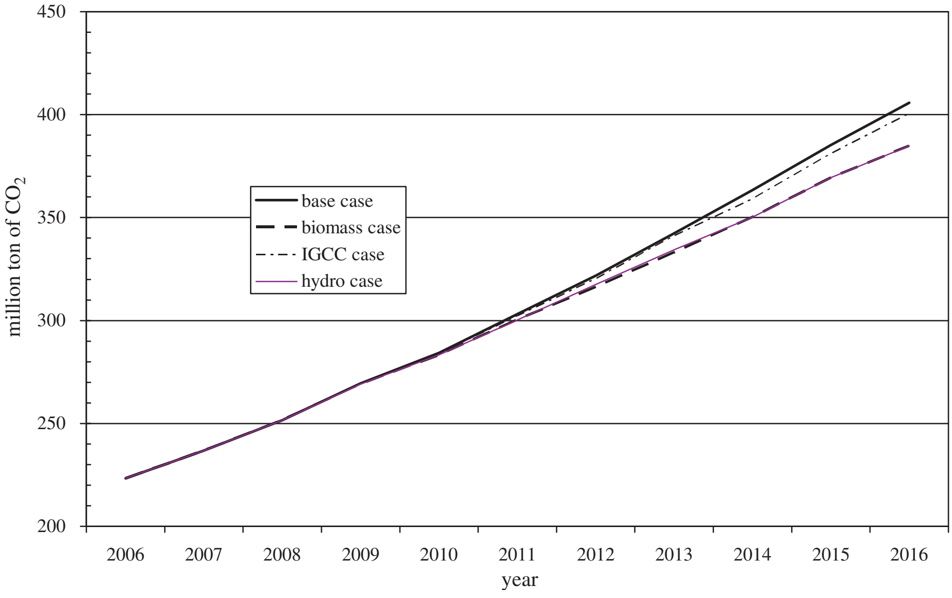


Fig. 6. Total CO_2 emission in all cases.

emission in the power plant construction, the cumulative net CO_2 emission in the economy during 2006–2016 would be 3365 million ton by the option of conventional pulverized coal thermal power plant of the additional capacity in the base case. Without consideration of construction of power plant's effect, the economy-wide CO_2 reduction in the biomass case and the hydro case is 69.4 million ton. The IGCC option in the IGCC case could be the alternative that reduces the net emission by 17.0 million ton.

Contribution of embedded emission in the plant's construction decreases the net CO_2 mitigation. The effect of indirect emissions from construction of power plant depends on the construction cost. In the base case, if the indirect emission of construction of additional power plant is taken into account, the CO_2 emission will increase around 22.36 million ton.

To produce the same amount of electricity, the IGCC case requires lower construction cost than the base case due to higher conversion efficiency. Renewable technologies generally require higher construction cost than coal technologies. The hydro case requires higher construction cost than the biomass case.

Substitution of the pulverized coal thermal capacity with biomass-based plants would result in the highest CO_2 mitigation option during 2006–2016. The embedded emissions of additional plant's construction of cleaner technologies are higher than the base case. Among all cases, the CO_2 emission is lowest in the IGCC case and is highest in the hydro case (see Table 5).

The fuel mix effect is the major contributor of CO_2 mitigation in the IGCC option due substitution of cleaner and efficient technologies. The structural effect slightly decreases the emission since intermediate demand of fuel in the IOA decreases. The demand effect is the major mitigation component in the biomass case and the hydro case due to switching from coal-based electricity generation to renewable energy. The structural effect slightly increases CO_2. It also induces the joint effect between structural and final demand effects.

Table 5
Economy-wide CO_2 emission effected by cleaner electricity generation technologies during 2006–2016

	Base case	Biomass case		IGCC case		Hydro case	
Direct emissions in power sector	1338.709	1334.855		1390.177		1338.706	
Economy-wide CO_2 emissions without CPP	3364.635						
CPP effects	22.356						
Compared with base case							
		Without CPP	Incremental by CPP	Without CPP	Incremental by CPP	Without CPP	Incremental by CPP
Increased from base case							
Fuel mix effect (FM)		–	–	(16.628)	–	–	–
Structural effect (ST)		0.020	–	(0.410)	–	0.017	–
Demand effect (DM)		(69.498)	0.931	–	(0.085)	(69.514)	3.413
Joint FM-ST		–	–	–	–	–	–
Joint FM-DM		–	–	–	Na	–	–
Joint ST-DM		0.070	Na	–	Na	0.059	Na
Joint FM-ST-DM		–	–	–	–	–	–
Total effects		(69.409)	0.931	(17.039)	(0.085)	(69.438)	3.413
Total effects with CPP	3386.991	(68.477)		(17.124)		(66.025)	

Note: CPP is the effect by increase of power plant construction. Unit: million ton CO_2.

The structural effect increases CO_2 emission in the biomass case and in the hydro case, since operation of biomass power plants result in higher intermediate demand of biomass fuels from agricultural sectors and indirectly induce higher inter-industrial transaction in the economy.

6. Conclusions and recommendations

The cleaner electricity generation technologies present lower CO_2 emissions in all cases compared to the base case. The initial investment for biomass and hydro power plants are high and consequently cause the increase in indirect emission by construction of the power plant. However, in the long run the net CO_2 mitigation in the power development plan would be success due to the shifting of electricity generation from conventional coal-based power plants to biomass and hydro power technologies. Selection of undecided capacity in the electricity generation expansion plan with biomass power plants would be a sound option for CO_2 mitigation. Its lead-time of construction is less than the hydropower and the construction cost is close to fossil-fired power plant.

During the studied period, contribution of emissions from the power sector to the whole economy is about 41% of the total energy-related CO_2 emission from the whole economy.

If renewable energy options are selected in the undecided capacity in the PDP2003 plan about 2% of CO_2 emission could be reduced in the power sector. In this situation, large biomass plantation is required. The contribution of supply-side options for CO_2 mitigation is not the only solution for global-warming-concerned energy planning. To alleviate the pressure on additional capacity requirement from increasing electricity demand, it also requires the demand side option.

Since there is no information on construction cost of the purchased hydro electricity from nearby countries, this study assumes that the country is responsible for the construction cost. Otherwise, the hydro case would be the best option for the net CO_2 mitigation option since the embedded emissions by construction of power plant could be avoided, the CO_2 emission was just moved from one to the other country. Moreover, in regard to the forecast of electricity demand in the power development plan, the government has to solve not only the problems of power expansion investment and CO_2 emissions, but also the increasing pressure on fuel requirement.

Acknowledgements

The authors would like to thank the Joint Graduate School of Energy and Environment, King Mongkut's University of Technology Thonburi for providing partial supports of this study. The authors also would like to thank Dr. Charles O. P. Marpaung and Prof. Dr Ing. Christoph Menke for their comments on the I–O analysis.

Appendix A

Table A1.

Table A1
The 50 sectors of the 1998 I–O table

	Sector name	Sector in original 180 × 180 I–O table
1	Crops	001–017, 024
2	Livestock	018–023
3	Forestry	025–027
4	Fishery	028–029
5	Coal and Lignite	30
6	Petroleum and Natural Gas	31
7	Metal Ore	032–035
8	Non-Metal Ore	036–041
9	Slaughtering	42
10	Processing and Preserving of Foods	043–048
11	Rice and Other Grain Milling	049–052
12	Sugar Refineries	55
13	Other Foods	053–054, 056–060
14	Animal Food	61
15	Beverages and Tobacco Products	062–066
16	Textile Industry	067–074
17	Paper Products and Printing	081–083
18	Chemical Industries	084–092

Table A1 (*continued*)

	Sector name	Sector in original 180 × 180 I–O table
19	Petroleum Refineries	093–094
20	Rubber and Plastic Products	095–098
21	Cement and Concrete Products	102–103
22	Other Non-metallic Products	099–101, 104
23	Iron and Steel	105–106
24	Non-ferrous Metal	107
25	Fabricated Metal Products	108–111
26	Industrial Machinery	112–115
27	Electrical Machinery and Apparatus	116–122
28	Motor Vehicles and Repairing	125–127
29	Other Transportation Equipment	123–124, 128
30	Leather Products	075–077
31	Saw Mills and Wood Products	078–080
32	Other Manufacturing Products	129–134
33	Coal Electricity	135
34	Lignite Electricity	135
35	Oil Electricity	135
36	Diesel Electricity	135
37	Natural Gas Electricity	135
38	Biomass Electricity	135
39	Hydro Electricity	135
40	Other Renewable Electricity	135
41	Pipe Line	136
42	Water Supply System	137
43	Other Construction	138–139, 141, 143–144
44	Public Works for Agriculture & Forestry	140
45	Construction of Electric Plant	142
46	Trade	145–146
47	Restaurants and Hotels	147–148
48	Transportation	149–156
49	Communication and Other Services	157–178
50	Unclassified	180

References

[1] Electricity Generating Authority of Thailand (EGAT). Aims of EGAT on power-plant-technology diversification: Reduction of natural gas dependency. Daily News newspaper 1/1/2004 (in Thai).

[2] Electricity Generating Authority of Thailand (EGAT). Thai energy news: Electricity supply deficiency in 2006. Available online: http://www.thaienergynews.com/query.php?ntype=1&newsid=30 10/1/2004 (in Thai).

[3] Electricity Generating Authority of Thailand (EGAT). Thai natural gas reserve. Available online: http://www.egat.co.th/misc/naturalgas.htm 10/1/2004 (in Thai).

[4] Electricity Generating Authority of Thailand (EGAT), Power development plan (2003). Generation System Development Planning Division of the Electricity Generating Authority of Thailand (EGAT), 2004.

[5] Energy Policy and Planning Office (EPPO). Should we select natural gas or coal for electricity generation? Available online: http://www.eppo.go.th/power/powerplant/4-ng.html 10/1/2004.

[6] Energy Policy and Planning Office (EPPO). Energy Policy and measures in 2003. Available online: http://www.eppo.go.th/doc/report-2546/5-policy-measure.html 8/14/2004.

[7] Energy Policy and Planning Office (EPPO). Energy Strategy for Competitiveness: Renewable energy-the new chance of Thailand. Available online http://www.eppo.go.th/admin/moeworkshop1/index.html (energy-strat2.ppt) 6/14/2004.

[8] Office of Environmental Policy and Planning (OEPP). Thailand's National Greenhouse Gas Inventory 1994-Final Report. Center of Applied Economic Research-Kasetsart University, Bangkok; 2000.
[9] Limmeechokchai B, Suksuntornsiri P, Shrestha RM. Implications of Carbon Tax on Economy-wide CO_2 Mitigation in Thailand: An Input–Output Analysis. In: Proceedings of the Joint International Conference on 'Sustainable Energy and Environment (SEE)'. The Joint Graduate School of Energy and Environment (JGSEE). Thailand; 2004.
[10] Proops JLR, Gay PW, Speck S, Schroder T. The lifetime pollution implications of various type of electricity generation: an input–output analysis. Energy Policy 1996;24(3):229–37.
[11] Marpaung, COP. Environmental Implications of Electric Utility Integrated Resource Planning: A Case of Indonesia. Dissertation report, Asian Institute of Technology; 1998.
[12] National Economic and Social Development Board (NESDB). 1998 Input–output tables of Thailand. Available online: http://www.nesdb.go.th; 11/08/2001.
[13] Electricity Generation Authority of Thailand (EGAT). General Information EGAT Power Development Plan 2003.
[14] Sirindhorn International Institute of Technology (SIIT). Implications of Carbon and Energy Taxes as Instrument for GHG Reduction in the Power Sector and Decomposing of Economy-Wide Change in Emissions with Taxes using An Input–Output Analysis: The case of Thailand 2004.
[15] Department of Alternative Energy Development and Efficiency (DEDE). Electric Power in Thailand 2002 2003.
[16] National Economic and Social Development Board (NESDB). Energy input–output tables. Personal communications 2002.
[17] National Economic and Social Development Board (NESDB). Gross Domestic Products, Available online: www.nesdb.go.th; 21/09/2004.
[18] Intergovernmental Panel on Climate Change (IPCC). Revised 1996 IPCC guidelines for national greenhouse gas inventories: Reporting instruction (Volume 1), Available online: http://www.ipcc-nggip.iges.or.jp; 3/11/2001.
[19] Intergovernmental Panel on Climate Change (IPCC). Revised 1996 IPCC guidelines for national greenhouse gas inventories: Workbook (Volume 2), Available online: http://www.ipcc-nggip.iges.or.jp; 3/11/2001.
[20] Intergovernmental Panel on Climate Change (IPCC). Revised 1996 IPCC guidelines for national greenhouse gas inventories: Reference Manual (Volume 3), Available online: http://www.ipcc-nggip.iges.or.jp; 3/11/2001.